USE OF COMPUTER MODELS TO PREDICT THE RESPONSE OF SPRINKLERS AND DETECTORS IN LARGE SPACES

Kathy A. Notarianni, P.E. and William D. Davis, Ph.D.
National Institute of Standards and Technology
Gaithersburg, MD 20899

SUMMARY

Measurements were made during fire tests conducted in an aircraft hangar with a ceiling height of 30.4 m. Fire gas temperatures and disk temperatures were measured above the fire and along the ceiling in locations corresponding to the expected location of detectors or sprinklers. Instrument locations were determined utilizing the computer fire models FPETOOL, DETACT-QS, and LAVENT. The results of the fire experiments were then compared to the predictions from the computer models in order to determine the limits of applicability of the models and to develop recommendations for use in large spaces. In the analysis conducted, computer fire models underpredicted the ceiling jet temperatures and thus are conservative in their activation predictions. For large spaces, a model should be developed that includes hot gas transport time and fire plume dynamics. In the ongoing phase of this project, a computational fluid dynamic model, HARWELL FLOW3D, is used to model the space. Initial comparisons between the computational fluid dynamic calculations and the experiment for the centerline plume temperatures are in reasonable agreement.

1. INTRODUCTION

Large spaces, such as those found in warehouses, historical buildings, atriums, and aircraft hangars, represent some of the most difficult fire protection challenges since they are frequently of historical significance, contain large quantities of fuel, and/or present special life safety problems. Accurate activation predictions are important in these large spaces, as timely detection of a fire is more difficult due to the distance heat and products of combustion must travel to reach detectors and sprinklers. An increased time to detection results in larger fires at the time of detection and larger fires to be suppressed by, for example, an automatic sprinkler system. Since fires frequently grow at an exponential rate, even a modest uncertainty in the prediction of the activation time may lead to a large uncertainty in the fire size used to predict the hazard.

There has been substantial effort to verify activation predictions in small and medium sized rooms, but little in large spaces [1]. Conducting verification experiments for large spaces is difficult due to the lack of availability of adequate facilities for live fire tests. The largest dedicated fire test facility in the United States is limited to a height of 18.2 m.

Why is model verification important? It is the responsibility of the user of a model to determine the suitability of a particular fire model for a given situation. A successful comparison of the model predictions with real-scale fire results helps the user make that decision. Of course it is impossible to validate a fire model fully, that is to test it against all possible real world situations. However, even limited model verification tests allow model developers to examine the accuracy of a model and identify the needs for future model development. It is critical that the user have comparisons of model predictions to a wide range of experimental data.

The Building and Fire Research Laboratory (BFRL) was given the opportunity to make measurements during fire calibration tests of the heat detection system in an aircraft hangar with a 30.4 m ceiling height near Dallas, TX. Three closed-door tests were conducted. Temperature profiles and visual test observations were similar for the three tests.

2.0 BUILDING LAYOUT

The aircraft hangar, pictured in figure 1, measures approximately 389 m long by 115 m deep (81 m to a firewall), and 30.4 m high. The hangar has seven bays and is capable of housing seven wide-bodied aircraft, side by side. Each bay is approximately 12.5 m in length. The bays are separated by 3.7 m deep draft curtains. A plan view of the test bay and the two adjacent bays is shown in figure 2.

3.0 TEST FIRE

The test fire was an array of nine pans, each 0.91 m x 0.91 m, totalling 7.5 m^2, arranged as shown in figure 2. Cloth wicks were draped between the pans to aid in fire spread after the ignition of one pan. The test fuel was isopropyl alcohol. Isopropyl alcohol burns with a luminous flame but produces very little visible smoke, and is commonly used in aircraft hangar test fires. The heat release rate of the fire was approximately 8250 kW. The fire was located on the floor in the center of bay #4, the center bay.

Six seconds after ignition of one pan, all pans were fully involved. Steady burning was maintained for approximately three minutes and thirty seconds. The observed luminous flame height during this phase averaged 6.4 m. This compares with 6.0 m predicted from Zukoski's correlation for pool-configured flames [2]. After three and one-half minutes, the flame height started to decrease. The fire was allowed to burn out. A picture of the fire at steady-state is shown in figure 3. The maximum temperature recorded at the ceiling directly over the fire was 73 °C.

4.0 MEASUREMENTS TAKEN

Figure 4 shows the instrumentation layout.

To measure the temperature and velocity of the ceiling jet, six temperature measurements were taken vertically below the ceiling east and west of the fire at radial distances of 1.5 m, 3.0 m, 4.6 m, and 6.1 m from the centerline of the fire. At each radial position, a thermocouple and calibrated metal disk (calibrated metal disks were used to simulate sprinkler links) were placed at 0.15 m and 0.91 m below the ceiling. Thermocouples were also placed at 0.30 m and 1.5 m below the ceiling. Assuming that the smoke and temperature flow together, the thermocouple readings can indicate the velocity and the position of the smoke.

To measure smoke filling in the fire test bay, thermocouples were placed to the east and west of the fire at 5.5 m radially. Thermocouples were placed vertically from the ceiling to the bottom of the draft curtain as shown in figure 4 to determine the layer height.

To measure the centerline plume temperatures, eight thermocouples were placed directly over the fire at 3.04 m intervals from the ceiling to 21.3 m below the ceiling.

To track the flow of smoke, a thermocouple was placed 25 mm directly under the draft curtains between the test bay and the adjacent bays. An array of four thermocouples was placed at the center of the east adjacent bay and of the west adjacent bay. Thermocouples were also placed 25 mm below the draft curtains at the far end of the east adjacent bay and at the far end of the west adjacent bay. Thermocouples were placed to the north and south of the fire, just below the ceiling.

5.0 FIRE MODELS

It is important to understand the physics of the computer models and the assumptions built into each code. FPETOOL, written by Nelson [3,4] and DETACT-QS, written by Evans and Stroup [5,6], are each based on experimental correlations developed by Alpert for steady-state fires [7]. These correlations give the maximum temperature and maximum velocity as a function of the heat release rate of the fire, the radial distance from the fire to the detector, and the height of the ceiling above the fire. These correlations assume a smooth, unconfined ceiling. They also assume that steady-state correlations can be applied to a growing fire over small time intervals. In both programs, the transport time of the smoke and hot gases from the fire to the thermal detector is neglected. Also in both programs, the detector is subject to the maximum temperature and velocity of the ceiling jet. FPETOOL accounts for the impact of the hot gases entrained into the ceiling jet on the temperature and velocity of the jet as it passes through the hot smoke layer; DETACT-QS does not. The expressions used in DETACT-QS and FPETOOL for temperature and velocity are independent of radius for r/h less than 0.18, which is assumed to be within the plume region.

LAVENT, written by Davis and Cooper [8,9,10], is similar to FPETOOL and DETACT-QS in that it assumes steady state correlations can be applied to a growing fire over small time intervals; and it also neglects the transport time of the smoke and hot gases from fire to thermal detector. LAVENT does account for the impact of the hot upper layer on the ceiling jet. The important difference between LAVENT and the other activation models is that LAVENT accounts for position of the thermal detector below the ceiling in the ceiling jet. The expressions for ceiling jet temperature and velocity used in LAVENT are independent of radius for r/h less than 0.2, which is assumed to be within the plume region.

HARWELL FLOW3D is a computational fluid dynamic or field model which represents a substantial departure from the zone model physics of the prior three models [11]. The basic equation set, the Navier Stokes equations, includes the momentum equation as well as the mass and energy equations. Zone models use only the mass and energy equations and rely on correlations to model the transfer of mass and energy from one zone to another. The physical space is set up as a two or three dimensional grid with the equation set being solved at the center of each grid cell. The calculation is time dependent with the fire being represented by a heat release rate. The transport time for the hot gases to reach the detectors and the three dimensional structure of the ceiling jet is included in the calculation. Turbulent heat transfer and gas viscosity depend on the choice of turbulence model and the set of constants used for each turbulence model. Radiation can be included in the calculation but for this plume, temperatures were low enough that radiation was judged unimportant. Physical obstructions, such as draft curtains, can be included in the calculation through the use of thin objects which obstruct the flow, but do not absorb energy.

6.0 PRELIMINARY RESULTS

Comparisons were made of the measured ceiling jet temperatures with the predictions of DETACT-QS, LAVENT, and FPETOOL, inside and outside of the plume region. Inside the plume region, both the FPETOOL and DETACT-QS computer programs underpredict the ceiling jet temperatures, thereby providing a conservative estimate of the time to activation of a detector or sprinkler. LAVENT predicts a greater temperature gradient in the vertical direction in ceiling jet than was measured. The predictions of LAVENT for the positions nearer to the ceiling are closer to the measured values, and thus more accurate than the DETACT-QS or FPETOOL predictions. For the positions further from the ceiling, the predictions of DETACT-QS and FPETOOL are closer to the measured values.

Outside of the plume region, the comparison of the measured and predicted ceiling jet temperatures is more accurate than inside the plume region. These measurement positions are on the other side of the main bay draft curtain. Flow around the draft curtain provides for some mixing and cooling, and the predictions more closely match the measurements. It should be noted, however, that none of the computer programs account for the draft curtains.

Simulations, using the field model, have been done using both two and three dimensional grids and initial comparison between calculation and experiment for the center line plume temperature gives reasonable agreement. Additional work remains to be done since the fire plume exhibits some asymmetric behavior. This effect and the noise introduced in the experimental measurements due to the time variations of the pan fires need to be addressed before a valid comparison between the experiment and the field model can be completed.

ACKNOWLEDGMENTS

This study was funded by the U.S. General Services Administration (GSA) and the National Aeronautics and Space Administration (NASA). Mr. Daniel Madrzykowski and Mr. Jay McElory assisted with the live fire tests. Special thanks to Mr. Dave Burkhart for obtaining permission for NIST to take measurements in the hangar, and to David Stroup and Phillip Tapper, the project liaisons.

REFERENCES

1. Walton, W.D., and Notarianni, K.A., A Comparison of Ceiling Jet Temperatures Measured in an Aircraft Hangar Test Fire with Temperatures Predicted by the DETACT-QS and LAVENT Computer Models, NISTIR 4947, National Institute of Standards and Technology, Gaithersburg, MD, 1992.

2. DiNenno, P. J. ed, SFPE Handbook of Fire Protection Engineering, Society of Fire Protection Engineering, Boston, MA, First Ed., 1988.

3. Nelson, H.E., FPETOOL: Fire Protection Engineering Tools for Hazard Estimation, NISTIR 4380, National Institute of Standards and Technology, Gaithersburg, MD 1990.

4. Nelson, H.E., FPETOOL User's Guide, NISTIR 4439, National Institute of Standards and Technology, Gaithersburg, MD 1990.

5. Evans, D., and Stroup, D. W., Methods to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings, NBSIR 85-3167, National Institute of Standards and Technology, Gaithersburg, MD, 1985.

6. Stroup, D. W., Evans, D.D., and Martin, P.M., Evaluating Thermal Fire Detection Systems, NBS SP 712, National Institute of Standards and Technology, Gaithersburg, MD, 1986.

7. Alpert, R.L., Calculation of Response Time of Ceiling Mounted Fire Detectors, Fire Technology, Volume 8 Number 3, August, 1972.

8. Davis, W.D., and Cooper, L.Y., Estimating the Environment and the Response of Sprinkler Links in Compartment Fires With Draft Curtains and Fusible Link-Actuated Ceiling Vents. Part

9. Davis, W.D., and Cooper, L.Y., User Guide for the Computer Code LAVENT., NISTIR 89-4122, National Institute of Standards and Technology, Gaithersburg, MD, 1989.

10. Davis, W.D., LAVENT: Link-Activated VENTs., SFPE Bulletin, Society of Fire Protection Engineers, Boston, MA, March/April, 1992.

11. FLOW3D Release 3.2: USER MANUAL, CFD department, AEA Industrial Technology, Harwell Laboratory, United Kingdom, October, 1992.

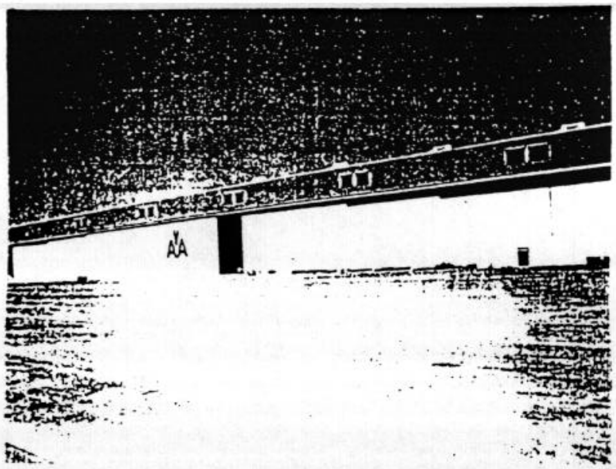

Figure 1. Picture of aircraft hanger

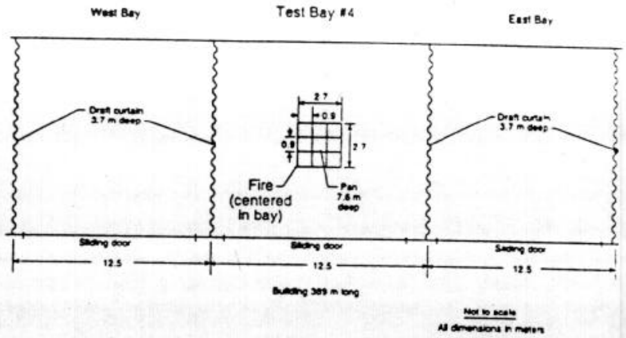

Figure 2. Plan view of test bay

Figure 3. Picture of test fire

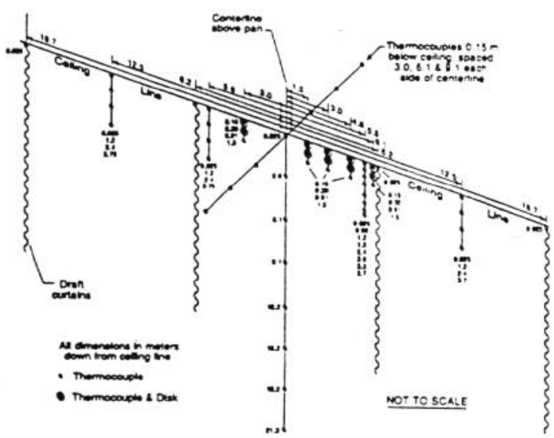

Figure 4. Instrumentation layout